Health Risk Analysis of the Rio de Janeiro Water Supply Using Geographical Information Systems

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Abstract

Assessment of health risk in population groups is based on environmental, socioeconomic, and health data. A geographic information system (GIS) was used to simultaneously analyze databases from distinct origins. The case of health risk related to vulnerability of water supply in the city of Rio de Janeiro, Brazil, was examined by using information on the water supply system as well as epidemiological and socioeconomic indicators. The water distribution system covers nearly all city territory and the main treatment plant produces water within the quality guidelines. However, important threats to the population's health remain due to the presence of contamination sources throughout the distribution system and vulnerable small springs. Problems detected involve characteristic city areas, comprising one-third of the total city population.

Keywords: water supply systems, health risk assessment

Introduction

Health risk is the result of a complex interaction between environment and population. Risk factors are comprised of a number of social, environmental, and health variables such as the presence of contamination sources, the geodynamics of contaminants in the environment, population behavior, and the accessibility of exposed groups to education and health care. The integrated analysis of health risks is based on the choice of specific environmental health indicators and their spatial projection (1). Data on each of these factors have different origins and constructive characteristics. The GIS have been used for the gathering, organization, and analysis of large databases on health and environment (2). These systems allow the capture, storage, manipulation, analysis, and display of georeferenced data—i.e., data related to graphic entities representing spatial elements.

The case of water supply in Rio de Janeiro is used here as an example of assembling risk maps from complementary and exchangeable information. Several Brazilian sources of information contain data on the water supply and health conditions. Four information layers were built using demographic and socioeconomic data, as well as data on the water supply system, the distributed water quality, and the number of infant deaths by diarrhea. These information layers were then analyzed.

About 95% of the households in the city of Rio de Janeiro are linked to the public water supply system, the main water treatment plant (WTP) of which (Guandú WTP, Figure 1) produces certified quality water. However, some persistent water supply

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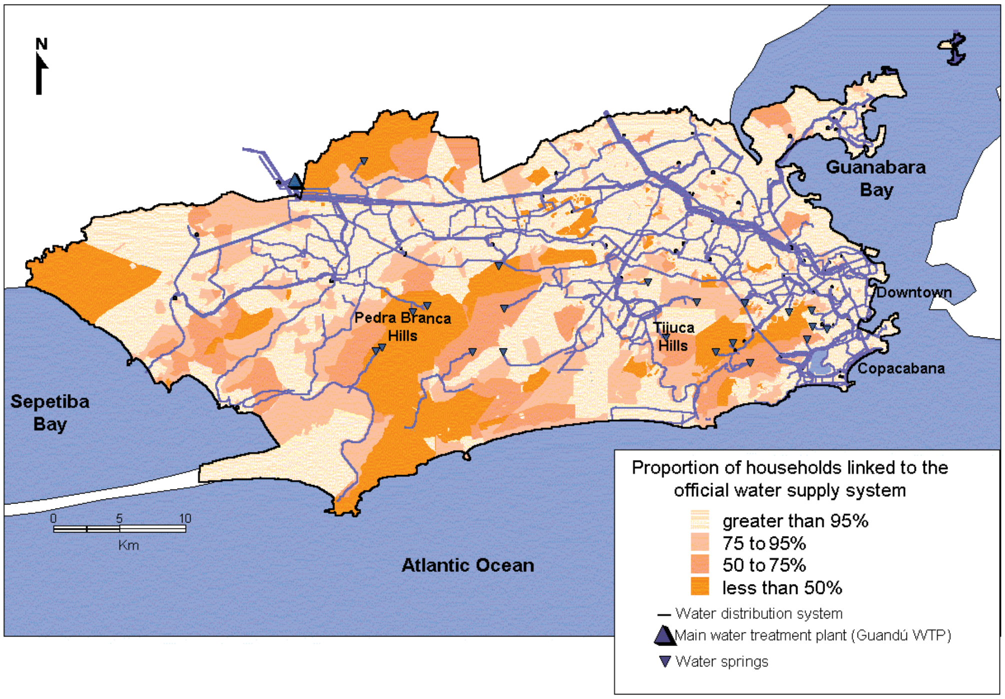

Figure 1 Water distribution system of Rio de Janeiro (location of pipes, Guandú WTP, and small water springs) and the household water supply in census tracts.

issues persist and may lead to negative outcomes in population health. Those issues worth mentioning include water contamination by microorganisms throughout the distribution system; the vulnerability of the system due to the contribution of small and untreated water sources (Figure 1); and, eventually, the absence of this service in some areas. Rio de Janeiro presents an extreme variability in land use for an urban area and a sharp topography, registered in postcards and social statistics. In the city mountainous area, poor settlements ("favelas") and luxury residences share contiguous neighborhoods. A preserved rain forest, protected by a national park, covers a large portion of the hills, where small water springs are localized.

This work aims to identify the main risks related to Rio's water supply as well as who and where the exposed population is. Procedures for assembling and cross-analyzing information layers related to the water supply and epidemiological data are described intending to show different ways of using GIS in ecological health analysis.

Data Acquisition and Management

Each information source constitutes one layer, exhibiting a distinct origin, purpose, and constructive characteristic, enabling spatial operations and population-at-risk calculations in a GIS environment. The city plan of the water distribution system demonstrates the capacity to serve portions of the city located around the pipes. However, the effective provisioning of households relies on other features, such as water pressure, flow regime, and the population's disposition to pay for this service. During the demographic census, individuals are asked about water origin (official system, wells, or local springs) and domestic provision. The answer to this question should be treated as a manifest about the predominant way the household is provided. Data on water quality are collected by monitoring programs that check water quality indicators (such as the presence of coliform bacteria) that do not imply an immediate health impairment and do not necessarily reflect the overall health risk conditions (3,4). Using epidemiological indicators for assessment of sanitation impact is limited by availability and quality of disease registers. Furthermore, a variation in indicators (e.g., infant mortality or diarrhea incidence rates) cannot be specifically attributed to water contamination because the indicators are also influenced by the subjects' existing educational and economic status and by their degree of health service access (5,6).

Census Tracts Layer

Approximately 6,400 census tract polygons were digitized from analog data obtained from the Brazilian census bureau (FIBGE), in the scale of 1:5,000. Demographic census variables, which include demographic and sanitation information, were associated to a map through census tracts codes.

Epidemiological Data Layer

The neighborhood polygons were obtained from the aggregation of census tracts and stored in a specific layer. Health registries—mortality and live born systems—were georeferenced to 153 neighborhoods.

Water Distribution System Layer

An analog map in scale 1:25,000 locating and identifying reservoirs, water treatment facilities, pumping stations, and main distribution network was obtained from the waterworks agency (CEDAE).

Water Quality Layer

Data on water quality were obtained from the State Environmental Protection Agency (FEEMA) monitoring program. A list of approximately 400 sampling station addresses was digitized and associated to 12,000 sample data referring to concentration of free chlorine, pH, fluoride, color, and turbidity, as well as the presence of total and fecal coliforms in the samples. To georeference sampling stations, the address was matched to a map in scale 1:2,000 for posterior calculation of coordinate pairs.

Identification of Risk Areas

The buffer technique was used to project areas of influence of risk factors. The choice of radius of influence was based on theoretical assumptions. Areas and population affected were identified using the following environmental, epidemiological, and sociodemographic criteria:

- Areas presenting high frequency of coliform contamination, indicating a high risk of water-related diseases transmission. These areas were defined by buffers of 1 kilometer (km) radius around the monitoring points where more than 20% of the samples presented contamination by fecal coliform.

- Areas predominantly served with waters of local origin—i.e., obtained from small springs that are concentrated in Tijuca and Pedra Branca hills (Figure 1). Due to increasing occupation of the hills, local water can be eventually contaminated by human solid and liquid wastes. These areas were defined by buffers of 2 km around small springs.
- Areas distant from the water distribution pipes, defined by buffers of 0.5 km around the arches representing the main distribution network. Large distances between households and the water distribution network can elevate the cost of connecting a house to the pipes, and can incorporate inadequate manipulation practices (7).
- Census tracts where more than 50% of the residents claimed not to be supplied by the official water supply system. This proportion may indicate a collective impairment to accessing the public service.

Table 1 identifies risk populations and areas pointed out according to the four mentioned criteria. Contamination of distributed tap water by coliform (criterion 1) comprises the majority of the population at risk, representing approximately 35% of total municipal population. Use of small local springs (criterion 2) or absence of water distribution network (criterion 3) can also represent risks for a significant portion of the population (10%), which is mainly localized in areas with low population density. A small portion of the population (about 2%) lives in areas where the supply is mostly obtained from alternative water sources (wells and local springs, not explored by the official sanitation company). However, it occupies a considerable area, nearly 16% of city territory. Those are the remaining areas of the city with low population density, where wells (in the case of the western semi-rural region) or springs (mainly in the high areas of the Tijuca Hills) have enough offer of water. These alternatives are impossible in the densely populated eastern areas.

An accumulation of risk factors is verified for some specific socio-spatial groups, which could explain the absence of household connection to the official water supply system. These groups are mainly localized in city areas served by low quality water supply service with incomplete urbanization, presenting both poor "favelas" and luxury residences. The epidemiological impact of the poor sanitation services on each of these groups is divergent. Privileged residents can obtain an alternative water supply, are more informed about water-related diseases, and can be promptly treated in health care facilities.

Table 1 Location, Number of Inhabitants, and Size of Risk Areas According to Different Water Supply Risk Criteria

Risk Criterion	Population (No. of Residents)	Area (km^2)	Location
Water contamination	1,900,000	349	Tijuca Hills northern slope, part of western region
Proximity to local springs	700,000	392	On the city elevated areas
Absence of water distribution pipes	600,000	156	Western region, isolated areas of the northern zone
Use of alternative sources of water	90,000	206	Western region and city, elevated areas

Distances from water sources to sampling points were calculated by using GIS operations. The correlation matrix relating water quality parameters and the distance to water sources is presented in Table 2. Fluoride and color decreases with the distance from the main WTP. Chlorine concentration does not suffer significant decay along the distribution pipes, perhaps reflecting the presence of re-chlorination stations in the distribution network. The proximity to local water springs implies lower mean chlorine concentrations and more frequent coliform contamination. These water sources were thus considered as vulnerability factors to the supply system.

Another risk criterion is the presence of a "sentinel event" in the neighborhood. Diarrhea deaths are dispersed in northern poor areas. In these areas, households are potentially supplied by water but occasional water contamination is observed. Diarrhea events were used to mark risk neighborhoods. According to this risk criterion, about 2.8 million of Rio's inhabitants can be considered as exposed to water-related diseases or suffering serious hampers in the access to health care services. In this case, the sentinel event should activate investigation of possibly related factors of each death: water quality and assistance received in primary health units (8).

Table 2 Correlation Coefficients between the Distance from Water Sources and Water Quality Parameters in the Sampling Stations (Pearson method, n=403)

	Fluoride	Chlorine	Color	Turbidity	Presence of Coliforms
Distance to the main water treatment plant	–.12*	.07	–.11*	–.02	–.09
Distance to local water springs	–.06	.11*	–.02	.05	–.13*

*Statistically significant associations (∝<.05)

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